PATENT SPECIFICATION

(11) 1 311 616

DRAWINGS ATTACHED

(21) Application No. 8669/71 (22) Filed 5 April 1971 (19)

(44) Complete Specification published 28 March 1973

(51) International Classification H05H 9/04

(52) Index at acceptance

H1D 18A1B2B 18A1B2Y 18A1B3 18A1BY 18A1Y 18AY 19X 19Y 20X 50

1 311 616

(54) METHOD FOR THE ACCELERATION OF IONS IN LINEAR ACCELERATORS AND A LINEAR ACCELERATOR FOR THE REALIZATION OF THIS METHOD

(71) We, VASILY ALEXEEVICH BOMKO, of kvartira 49, ulitsa I.Garkushi 3, EVGENY IVANOVICH REVUTSKY, of kvartira 3, ulitsa P.Morozova I, BORIS IVANOVICH RUDIAK, of kvartira 16, ulitsa P.Morozova I, and ANATOLY VASILIEVICH PIPA, of kvartira 33, ulitsa Tankopia 29/I, all Kharkov, Union of Soviet Socialist Republics, all citizens of the Union of Soviet Socialist Republics, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to linear accelerators, and more specifically to methods for the acceleration of ions in linear accelerators and to linear accelerators for realization of such methods.

In the prior art, there is a method for the acceleration of ions in a linear accelerator which is a cylindrical cavity with drift tubes. This method is based on the excitation of an r.f. electromagnetic standing wave in the E_{010} mode, in which case the electric field is uniformly distributed along the axis of the resonator. In this case, because of the requirement for synchronism, acceleration can be effected only at a single value of the accelerating field strength.

A disadvantage of this method is that the accelerated particle beam at the output from the accelerator can only have one value of energy for which the accelerator has been designed. On the other hand, most research and development programmes may be markedly extended, if the final energy of the accelerated particles can be variable within broad limits.

Intermediate energies have been obtained on the heavy-ion linear accelerators at Berkeley, U.S.A., and Manchester, Great Britain, by selecting the tilt of the accelerating field excited in the E_{010} mode.

Among the disadvantages of this method are the impossibilities of continuously varying the energy of the accelerated particles, more than a two fold loss of beam intensity, increased energy spread, and impaired stability of accelerator operation.

Another method for obtaining accelerated particles with intermediate energies is based on the use of a chain of single uncoupled resonators with r.f power supply. By cutting off the r.f. supply to a certain number of the final resonators, it is possible to obtain beams with the energy attained at the excited resonators.

Among the disadvantages of this method are the difficulties of feeding the chain of uncoupled resonators with r.f. power in phase and the complex design and the low efficiency of the accelerator because of considerable additional losses of r.f. power on the many end walls in the chain of resonators.

Neither of these methods offers a means for the continuous variation of the energy of accelerated particles.

According to the present invention there is provided a method of accelerating ions in a linear accelerator of a drift tube cavity type, employing a standing r.f. wave, enabling the final energy of the accelerated-ion beam to be varied continuously by adjusting the extent of a region with a uniform distribution of an accelerating field along the cavity axis, and said adjustment of the extent of said region is realized by deformation of the field distribution corresponding to E_{011} mode, excited in said cavity.

According to another aspect of the invention there is provided a linear accelerator adapted to realize a method as set forth in the preceding paragraph, said linear accelerator comprising: a cavity resonator with drift tubes; tuners arranged on a side wall of said resonator; an additional tuning means enabling adjustment of the extent of the region with a uniform distribution of the accelerating field established by transformation of the field distribution of the E_{011} mode and made in the form of a conducting

post installed on an end wall of said resonator near said side wall parallel with the axis of the resonator and capable of being moved parallel to that axis.

The invention will be more fully understood from the following description of preferred embodiments when read in connection with the accompanying drawings wherein:

Figure 1 is a plot showing the distribution of an accelerating field along a resonator excited in the E_{011} mode;

Figure 2 shows the construction of a linear accelerator in accordance with the invention;

Figure 3 is a plot showing the frequency of the E_{011} mode and the frequencies of the nearby modes as functions of the length of the post inserted into the resonator of Figure 2; and

Figure 4 shows the spectra of some of the intermediate beam energies obtained in an experiment on a linear accelerator designed for a maximum proton energy of 9 MeV.

A preferred method for the acceleration of ions consists in that acceleration is accomplished by establishing a region in which the accelerating field is distributed uniformly and the extent of which can be shorter than a cavity length. Ordinarily, when the E_{011} mode is excited in the cavity of a linear accelerator with drift tubes all cells of which are tuned to resonate at the same frequency, the distribution of the E_{011} mode electric field along the axis obeys the cosine law (curve *a* in Figure 1).

The region in which the accelerating field is distributed uniformly and the extent of which can be variable at will is realized in the linear accelerator of Figure 2 which is a cylindrical cavity 1 with drift tubes 2, tuners 3 arranged on its side wall, and an additional tuning means made in the form of a conducting post 4 installed on an end wall of the resonator near its side wall so that it can be moved parallel to the axis of the cavity. By varying the length by which the post 4 is inserted into the resonator, one can shift the node of the electric field along the axis of the cavity and, as a result, reduce the field strength represented by the right-hand branch of curve *b* in Figure 1, whilst by varying the depth of insertion into the resonator of the tuners 3, one can produce a region with a uniform distribution of the field strength represented by a left-hand branch of curve *b* in Fig. 1 and a steep downward jump of the accelerating field.

If the extent of said region with the uniform distribution and an ideally steep downward jump of the accelerating field is changed, the energy of the accelerated particles will also change in a jump, in step with the change of energy across one accelerating period. In practice, the downward jump is gradual rather than abrupt. Therefore, it is possible, by varying the slope of the jump, to change energy continuously within each step, corresponding to the change of energy across one accelerating period.

In the limiting case, by adjusting the depth of insertion into the resonator of the tuning post 4 and the tuners 3, it is an easy matter to obtain a uniform distribution for the accelerating field strength along the entire cavity owing to the said deformation of the field excited in the E_{011} mode.

Within certain limits, there is a possibility of establishing regions with a uniform distribution of field strength the extent of which is shorter than cavity length by means of deforming the left-hand branch of field distribution in the E_{011} mode and changing this extent solely by means of the tuners 3. However, in this case, the control is more difficult since it involves a considerable increase in the size of the tuning means. Besides there remains the right-hand branch of the field (represented by a curve *c* in Figure 1) which results in an increased energy spread of the beam of accelerated particles.

In actual operation of the accelerator, the continuous variation of the energy of accelerated ions is accomplished by moving the post 4 and the tuners 3 according to a predetermined program under which the length of post 4 inserted into the cavity and the depth of insertion into the cavity of the tuners 3 are calibrated in advance according to the required energy of the accelerated particles. This adjustment can be accomplished automatically. Furthermore, the length of the post 4 inserted into the cavity 1 and the depth of insertion of the tuners 3 can be varied from the outside, without any impairment of the vacuum in the cavity.

The stability of the characteristics of the accelerated beam in the face of changes in the energy of the accelerated particles can be ensured by increasing the separation between the resonant frequency f_{011} of the cavity, corresponding to the transformed E_{011} mode, and the frequencies f_{010} and f_{012} (Figure 3) of the nearby transformed modes, as the length of the post 4 immersed into the cavity 1 (Figure 2), is increased. The stability of the accelerating field is enhanced accordingly.

As an example of an embodiment of the acceleration method disclosed herein, we quote the results obtained on a linear proton accelerator with a maximum design energy of 9 MeV. This accelerator operated in an experimental program, with the continuously variable final energy of accelerated particles. Energy change was accomplished remotely. Some of the spectra of the beams accelerated under conditions of energy variation are shown in Figure 4. The energy of accelerated particles is represented by the abscissa and the relative intensity of the beams at the

output of the accelerator is represented by the ordinate.

The slight decrease in beam intensity with decreasing energy of the accelerated particles seen in the spectra of Figure 4 does not stem from the essence of the acceleration method disclosed herein, but is due to the type of beam focusing used in acceleration. In the case on hand, use was made of grid focusing, with the result that for some of the length of the accelerator where the accelerating field was not applied, the beam was not focused either, and some of the accelerated particles were lost. No loss of beam intensity occurs when the accelerated beam is focused by quadrupole magnetic lenses installed in the drift tubes.

The above described method for the acceleration of particles enables the energy of the accelerated particles to be variable continuously within broad limits (from one-third to the maximum energy of the accelerator) without any loss in the intensity of the accelerated beam. This acceleration method, in conjunction with the additional tuning means made in the form of a conducting post installed in an end wall of the cavity near its side wall in parallel with the axis of the cavity and capable of being moved along its axis, when used in a linear accelerator intended to realize this method, ensures high monochromaticity and stability of the characteristics of the beam with time without posing stringent requirements for the accuracy of the elements of the accelerating structure.

It is very desirable that any linear accelerator can be switched over to varied beam energy operation with ease and with only minor changes in its construction.

The additional tuning means for beam-energy control disclosed herein is very simple in design. The principle underlying the method for final energy variation and the construction of the tuning element make it possible to accomplish this variation automatically to a pre-determined program.

A further advantage of the acceleration method dicslosed herein is that it can be realized on the prior art linear accelerators with only minor changes in construction and, as a consequence, without additional capital outlays.

WHAT WE CLAIM IS:—

1. A method of accelerating ions in a linear accelerator of a drift tube cavity type, employing a standing r.f. wave, enabling the final energy of the accelerated-ion beam to be varied continuously by adjusting the extent of a region with a uniform distribution of an accelerating field along the cavity axis, and said adjustment of the extent of said region is realized by deformation of the field distribution corresponding to E_{011} mode, excited in said cavity.

2. A linear accelerator adapted to realize a method according to claim 1, comprising: a cavity resonator with drift tubes; tuners arranged on a side wall of said resonator; an additional tuning means enabling adjustment of the extent of the region with a uniform distribution of the accelerating field established by transformation of the field distribution of the E_{011} mode and made in the form of a conducting post installed on an end wall of said resonator near said side wall parallel with the axis of the resonator and capable of being moved parallel to that axis.

3. A method for accelerating ions in a linear accelerator substantially as herein described with reference to the accompanying drawings.

4. A linear accelerator adapted to realize the method according to claim 3, the linear accelerator being substantially as herein described with reference to the accompanying drawings.

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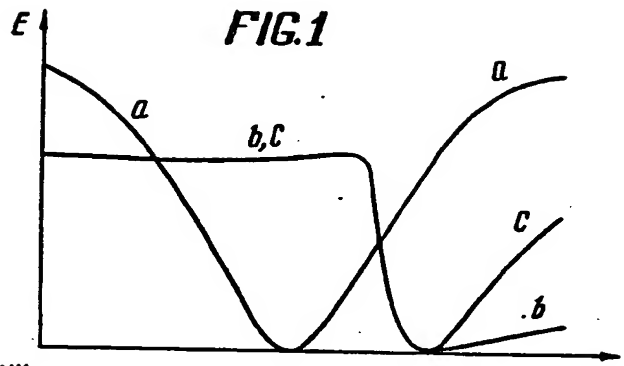
Printed for Her Majesty's Stationery Office by Burgess & Son (Abingdon), Ltd.—1973.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1311616 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1



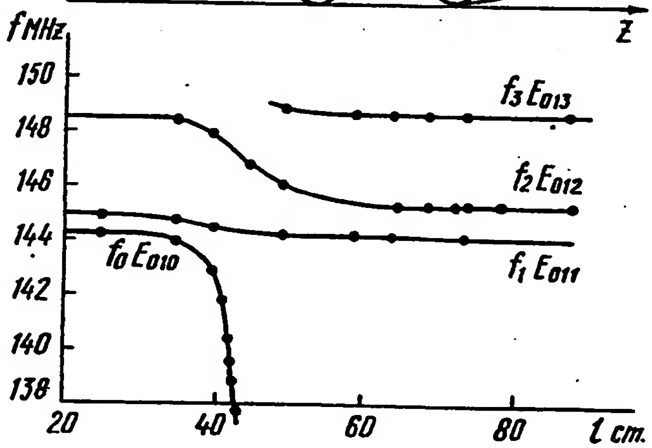


FIG.3

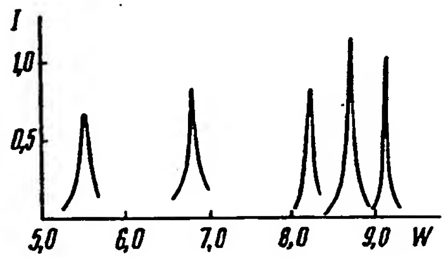


FIG 4

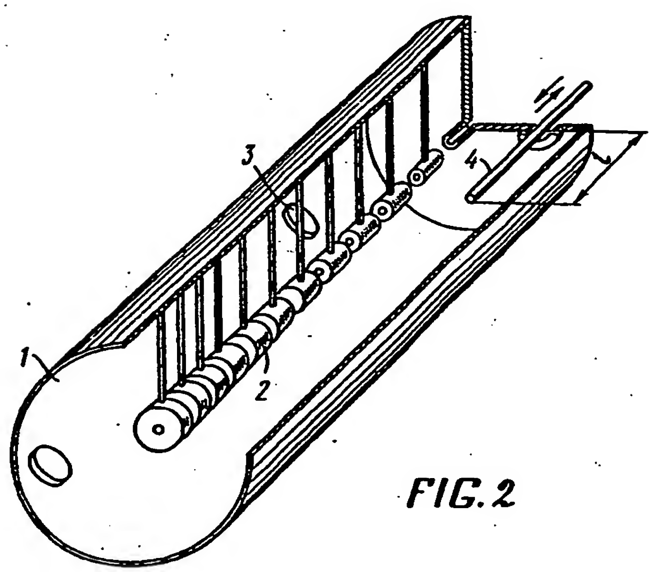


FIG. 2